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Original paper

Assessment of the variation in CT scanner performance (image quality and Hounsfield units) with scan parameters, for image optimisation in radiotherapy treatment planning

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ABSTRACT

Purpose: To define a method and investigate how the adjustment of scan parameters affected the image quality and Hounsfield units (HUs) on a CT scanner used for radiotherapy treatment planning. A lack of similar investigations in the literature may be a contributing factor in the apparent reluctance to optimise radiotherapy CT protocols.

Method: A Catphan phantom was used to assess how image quality on a Toshiba Aquilion LB scanner changed with scan parameters. Acquisition and reconstruction field-of-view (FOV), collimation, image slice thickness, effective mAs per rotation and reconstruction algorithm were varied. Changes were assessed for HUs of different materials, high contrast spatial resolution (HCSR), contrast-noise ratio (CNR), HU uniformity, scan direction low contrast and CT dose-index.

Results: CNR and HCSR varied most with reconstruction algorithm, reconstruction FOV and effective mAs. Collimation, but not image slice width, had a significant effect on CT dose-index with narrower collimation giving higher doses. Dose increased with effective mAs. Highest HU differences were seen when changing reconstruction algorithm: 56 HU for densities close to water and 117 HU for bone-like materials. Acquisition FOV affected the HUs but reconstruction FOV and effective mAs did not.

Conclusions: All the scan parameters investigated affected the image quality metrics. Reconstruction algorithm, reconstruction FOV, collimation and effective mAs were most important. Reconstruction algorithm and acquisition FOV had significant effect on HU. The methodology is applicable to radiotherapy CT scanners when investigating image quality optimisation, prior to assessing the impact of scan protocol changes on clinical CT images and treatment plans.

1. Introduction

The quality and geometric fidelity of CT images used in radiotherapy treatment planning must be sufficiently high to allow the accurate outlining of the tumour volume and organs at risk. Inaccuracies at the outlining stage can represent a significant source of error in the radiotherapy process [1–4]. The American Association of Physicists in Medicine (AAPM) recommends that CT scan protocols are developed and tailored for specific disease sites or anatomical regions [5]. The process of protocol optimisation requires that scan protocol parameters are adjusted to provide good image quality for the clinical imaging task at hand, whilst delivering a reasonable level of radiation dose that is clinically justified [6].

For CT scans which will be used in radiotherapy treatment planning there is another important requirement. The CT Hounsfield units for different tissue types must not vary significantly from the values used in the calibration curve within the treatment planning system (TPS). The TPS calibration curve allows the conversion of HU values into relative electron density (RED). In some TPSs this conversion is to physical density. If there is a mismatch between HU values in the CT image for specific tissue types, and the HU values in the TPS calibration curve which is used, the result will be an error in the dosimetric accuracy of the treatment plans produced [7,8]. When several calibration curves can be used within a TPS, there is opportunity to use different CT scan protocols for different body regions. Although restricting the number of calibration curves is an approach used in some centres to reduce the

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risk of incorrect selection and the work associated with quality assurance testing, this approach limits the opportunity for image optimisation. The settings in a CT scan protocol will significantly affect image quality [9–11]. However, before any adjustment of scan settings is made to improve image quality or reduce dose, it is helpful to assess any changes in scanner performance through use of an image quality phantom. In addition to assessing any changes in image quality metrics, such as contrast-noise-ratio or high contrast spatial resolution, the change in HU values should also be noted. This will allow quantification of any dose change in the radiotherapy planning process or a decision to be made about the need for a new calibration curve in the TPS. A number of recommended tolerances for HU or relative electron density values used in the TPS calibration curve are available in the literature, both from experimental work and in published professional guidance documents [12–15]. A recent literature review concluded that HU tolerances of ± 20 HU for soft tissue and ± 50 HU for bone and air corresponded to a 1% or lower dose change in the TPS calculation [16].

A number of studies have documented the performance of some types of radiotherapy CT scanners [17,18]. A few of these have assessed some aspects of the performance of CT scanners made by Toshiba (Toshiba Medical Systems Corporation, Otawara, Japan) CT scanners. Coolens et al. investigated a 320 slice Toshiba Aquilion One scanner which was to be used to support radiotherapy treatment planning [19]. A wide range of parameters were assessed for their impact on spatial resolution, contrast to noise ratio, image slice width, and radiation beam width. The review of HU variation was confined to the changes arising from selection of different acquisition field of view options and for different positions within the scan volume. However, in general, radiotherapy centres tend to select the larger bore CT scanner models, rather than the smaller bore scanners such as the Aquilion One. The CT scanner evaluation group ImPACT published comprehensive technical reports for different scanners [20,21]. Some large bore radiotherapy scanners were included in their detailed technical evaluations but not the Toshiba Aquilion LB scanner. The reports showed how changes in scan parameters affected image quality parameters. There was, however, no mention of HU value changes with scan parameters. On the Toshiba Aquilion LB scanner Zurl et al. investigated HU changes for different tube voltage settings, some reconstruction filters, acquisition field of view settings, slice thickness and tube current [22]. This study, however, focused on the HU change and did not provide any results of image quality measures. The purpose of this work is to provide data on typical changes in both HU and image quality parameters resulting from adjustment of a wide range of scan parameters. The specific CT scanner considered in this work was a Toshiba Aquilion LB scanner. The information can be used to enable the optimisation of head and neck radiotherapy CT scan protocols. This work defines a test methodology which is applicable when assessing performance of other makes and models of CT scanners used in radiotherapy.

2. Method

The Toshiba Aquilion LB CT scanner used in this work was a seven year old third-generation CT scanner with a Gadolinium oxysulphide solid state detector which could acquire up to 16 slices per rotation [23]. It could operate in sequential or helical scanning mode. The gantry aperture was 90 cm in diameter. Operating tube voltage options were 80, 100, 120 or 135. Tube current could be set at intervals between 10 and 500 mA. Tube current could also be set to modulate automatically using the on-board Sure Expose software. Options for the acquisition field of view were (XL) 700, (LL) 550, (L) 400, (M) 320 and (S) 240 mm in diameter. One of two physical beam shaping filters in the gantry was selected according to the acquisition FOV chosen: one filter was for head mode with FOVs 240 and 320, and a second filter for body mode with FOVs 400, 550 and 700. The X-ray tube was dual focus, with small focus being 0.9 mm × 0.8 mm and broad focus 1.6 mm × 1.4 mm. The focal spot size was selected automatically and dependant on the combination of tube current, slice thickness and field of view chosen by the operator. Options for image slice widths were 0.5, 1, 2, 3, 5, 8 and 10 mm and the maximum X-ray beam width at the isocentre was 32 mm. Helical pitch could be varied from 0.625 to 1.5. The image matrix size was 512 × 512 pixels. The Boost image processing setting was selectable to reduce noise and streaking artefacts caused by photon starvation through wide body regions such as the shoulders. A number of reconstruction algorithms were available for use depending on the type of imaging being undertaken. Details of the groups of algorithms investigated in this study are given in Table 1. A selection of algorithms was chosen from the different body regions groups, focusing on head and body algorithms. The existing algorithm in the head and neck protocol that was to be optimised was a body algorithm FC13. Higher numbered algorithms within a particular group were sharper than those with a lower number. Dose indication was given on the scanner as CT dose index volume (CTDIvol) and dose-length-product (DLP). Accuracy of CTDI had been checked and was within 10% of the indicated value. The operating software on the scanner was Aquilion LB version 3.35. The scanner was subject to a regular quality control programme which included carrying out air calibrations at the interval recommended by the manufacturer.

Table 1
Toshiba CT reconstruction algorithms [21,23].

Algorithm names	Intended body region
FC11, FC12, FC13, FC14, FC15	Body – without beam hardening correction (BHC)
FC20, FC21, FC22, FC23, FC24, FC25	Head – with BHC; fine grain size
FC62, FC63, FC64, FC65, FC66, FC67	Head – with BHC; coarse grain size
FC41, FC42, FC43, FC44	Head – without BHC

A Catphan CT phantom (Phantom Laboratory, Greenwich, USA) was used for this work. The phantom diameter was 15 cm and its length was 20 cm. The phantom could be used to measure high contrast spatial resolution, low contrast resolution and noise, Hounsfield unit values for a range of different relative electron density (RED) materials, the visibility of low contrast spheres with varying slice width, HU uniformity and noise across a plain section. A detailed technical description of the five modules used in the phantom is given in Table 2. The Catphan was considered an appropriate tool since the diameter is a reasonable match for an adult head. When a comparison was made of the Catphan phantom and the head of the Alderson Rando phantom (Alderson Research Laboratories, Inc., Long Island, USA) with the scanner set to modulate the tube current automatically, the typical tube current for the Catphan was generally within 13% of that for the head of the Rando phantom.

Tests were carried out varying one scan parameter at a time, and noting both the image quality metrics and the HU variation. The parameters adjusted were acquisition field of view, reconstruction field of view, reconstruction algorithm, acquisition slice thickness, reconstruction slice thickness, effective mAs. The scan protocols used are given in Table 3. All scans were carried out using helical scanning, 120 kV and helical pitch of 0.938. The Boost image processing was switched on to match clinical practice. Three repeat measurements were made to check for consistent scanner performance. The kilovoltage setting was kept constant since it is well documented that variation will result in a change of several hundred HU between different kV settings [8,17,24,22].

For the image quality assessment the image was electronically zoomed to a field of view diameter of 200 mm, except where the reconstructed FOV was already 200 mm. Window width and level were adjusted to optimise visibility of details for the high contrast spatial resolution groups and the low contrast spheres. Using module CTP515, assessment of the visibility of low contrast circles by counting the